U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND

Introduction to Weapons for High-Throughput Materials Discovery for Extreme Conditions

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ARL Lead, Long Range Distributed & Collaborative Engagements Essential Research Program

Long Range Precision Fires Army Modernization Priority

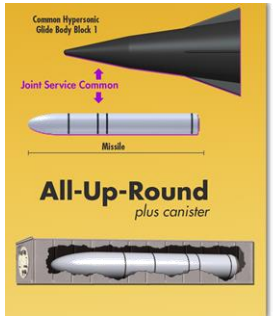
Hypersonic Flight Army Priority Research Area

ORIENTATION TO ARMY WEAPONS

Weapons-centric Army branches:

- Field Artillery
- Air Defense Artillery
- Armor
- Infantry
- Aviation

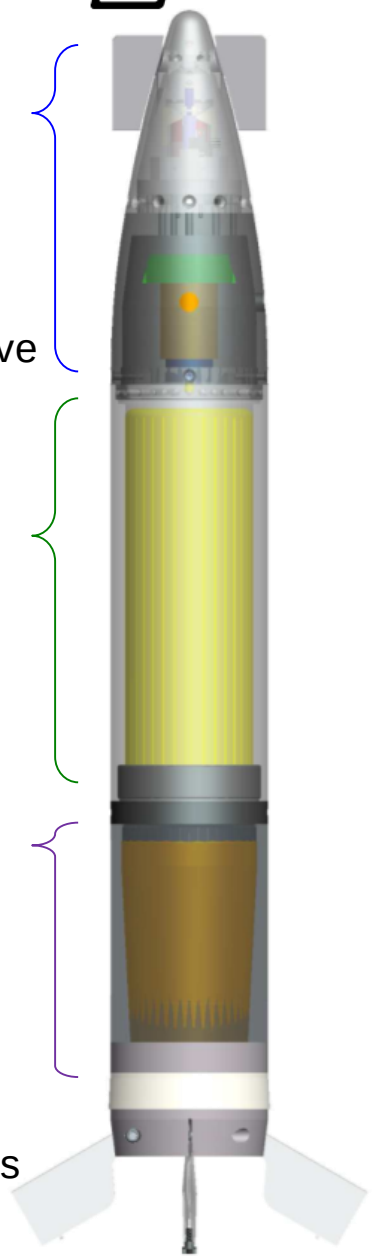
Two broad Army weapons classes: Rockets/Missiles and Guns



Army focus on Land Warfare differentiates scope from other Services

- Smaller
- Cheaper / Higher Magazine Depth
- More expeditionary…

ARMY WEAPON COMPONENTRY
- WHAT IS IN A MUNITION? -



Guidance
- Sensors: visible/infrared imagers, antennae, accelerometers, gyroscopes, magnetometers
- Electronics: power/signal conditioning, radios
- Real-time processors
- Control mechanisms: electromechanical actuation of aerodynamic and/or impulsive control to steer vehicle
- Power supplies: thermal batteries, super-capacitors

Lethal mechanism
- Blast-fragmentation warhead: fuzing/ignition, high-explosive, metal case
- Shaped-charge/explosively-formed penetrator: fuzing/ignition, high-explosive, ductile metal liner (e.g., trumpet)
- Kinetic energy penetrator: high-density metal rod/slug

Post-launch propulsion
- Solid-rocket motor: ignition, nozzle/pressure vessel, propellant
- Air-breathing propulsion (ramjet): ignition, inlet/grain/mixing/nozzle, propellant

Structures
- Mechanical, thermal, electro-magnetic, aerodynamic functionality and weapon packaging (e.g, size/weight) constraints
- Joints, gun rifling engraving bands, gun gas obturators, sabots, launcher interfaces (e.g., rail, tube), stability and control surface deployment features, …

EXTREME CONDITIONS OF ARMY WEAPONS

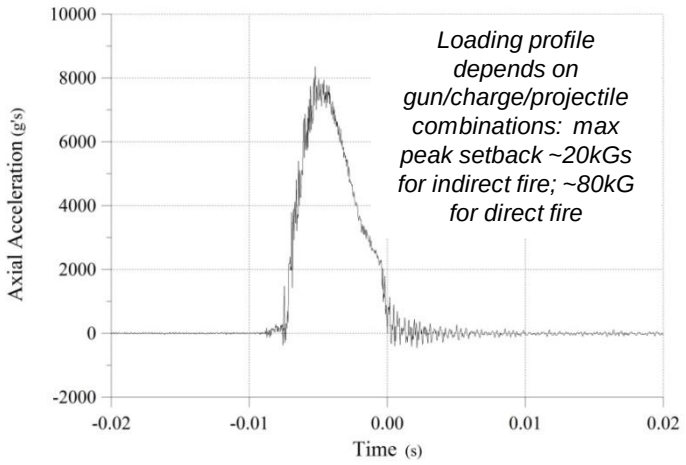
High Thermal Load (e.g., hypersonic flight)

High Mechanical Load (e.g., gun launch)

EXTREME CONDITIONS OF ARMY WEAPONS

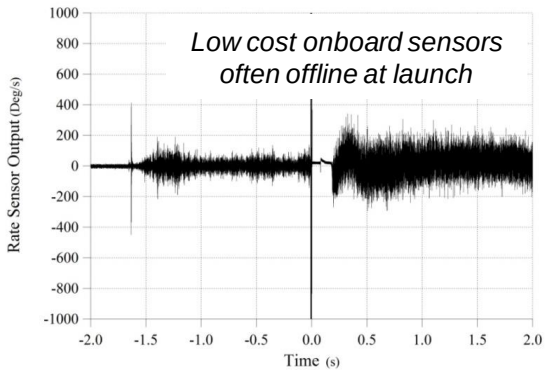
EXTREME CONDITIONS OF ARMY WEAPONS
- HIGH LAUNCH (MECHANICAL) LOADING -

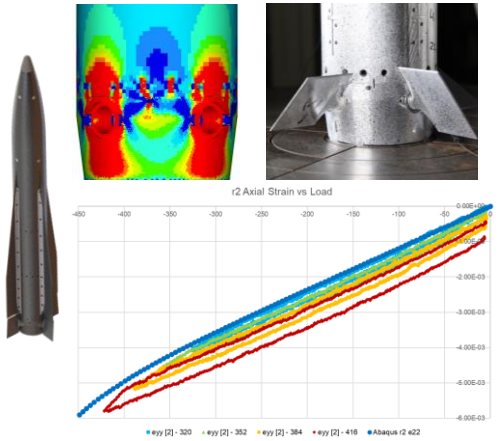
Extreme Environment Challenges:
- Gun-launch set-back: large acceleration up to muzzle velocity encountered in-bore from propellant gas generation/pressure on projectile base
- Gun-launch set-forward: high-frequency vibration experienced at muzzle exit from release of body from propellant base pressure and tube wall constraints
- High spin rate



Current Approach:
- Strong reliance on known materials (steel, depleted uranium, tungsten, copper, TNT-based explosives, HTBP/AP and NC-NG propellants)
- Computational modeling of coarse features
- Analytical modeling of failure criteria (low cycle fatigue)
- Experimental verification (compression, shock table, air gun, powder gun)

Gaps:
- Excess design margin for structural integrity results in parasitic mass which reduces propulsion, guidance, warhead performance
- Inability to incorporate technologies (e.g., motor configurations, delicate guidance components) into environment





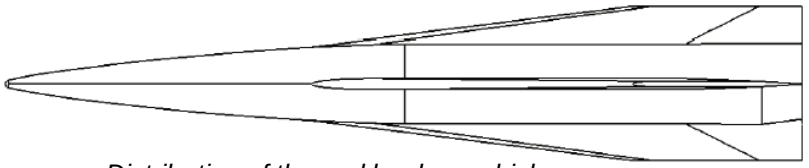
Catastrophic failure of launch packages with existing materials subject to extreme mechanical loading

EXTREME CONDITIONS OF ARMY WEAPONS
- HIGH FLIGHT (THERMAL) LOADING -

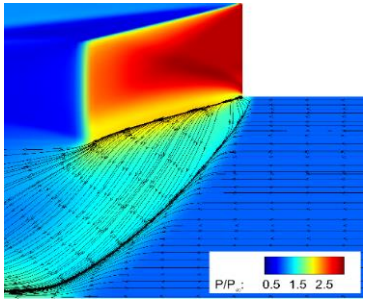
Extreme Environment Challenges:
- High temperature and heat flux distribution on vehicle

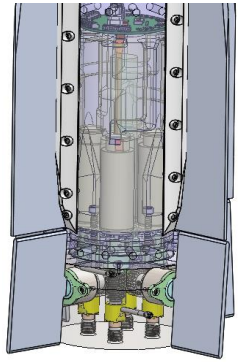
Current Approach:
- Polymer/carbon-carbon composite architectures for majority of body (acreage) adapted from space community
- High-density metals (e.g., tungsten) and ceramics for leading edges

Gaps:
- Cost, process time, availability
- Thermal and mechanical survivability per unit parasitic mass
- Simple (2D) configurations
- Joining techniques
- RF and IR sensor aperture transparency and thermal cycling tolerance
- Integrated performance and diagnostic materials
- Lack understanding of material/ processing behavior and relationship to performance metrics
- Lack of understanding/uncertainty in information essential for coupled component tech design and exploitation to discover novel component tech (e.g., heat flux into the vehicle for thermal protection technologies) resulting in long design cycle times (stove-piped) reduce system capability and increase cost

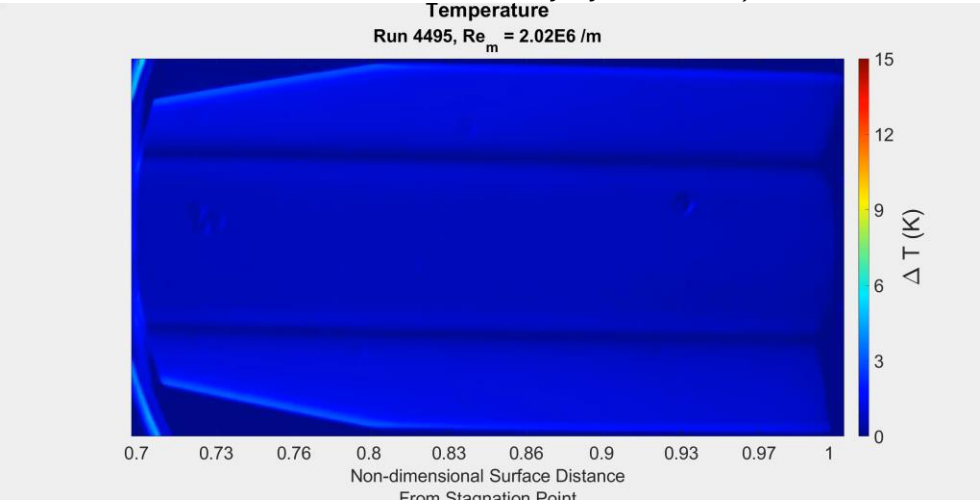


Distribution of thermal load on vehicle depending on flight conditions (leading edges, control surface junctures)





Prediction and experiments on complex/uncertain chemistry and physics of aero-thermodynamics of high-speed flight (shock-boundary layer and shock-shock interactions, boundary layer transition)



MATERIALS DISCOVERY FOR ARMY WEAPONS
- SUMMARY NEEDS -

Discovery of Materials for Novel Weapons Tech:
- Control mechanisms, sensors, electronics, power supplies, and processing for guidance components
- Propulsion mechanisms, propellants for gun and post-launch propulsion components
- Warhead mechanisms, cases/liners, penetrators, and explosives for lethal payload components

Discovery of Materials for Weapons Survivability under High Mechanical and Thermal Loading:
- Expand envelope to higher loading or more available materials to existing loads

Metric	Objective	Comments
Launch (mechanical) load	• >100,000 Gs over 10ms peak set-back launch load • 10% peak set-back over 0.1ms set-forward launch load	Yield strength vs plastic strain better than steel and aluminum aerospace alloys (e.g., 7075, 6061)
Flight (thermal) load	• > 1600°C temperatures • > Mach 6 at sea-level through >20km flight conditions*	* Additional government-provided details (e.g., steady and transient heat flux, shear and normal surface loads on vehicle and control surfaces, etc.) outside scope of unclassified 6.1 research
Launch and flight load	• >20,000 Gs over 10ms peak set-back launch load • 10% peak set-back over 0.1ms set-forward launch load • > 1600°C temperatures • > Mach 6 at sea-level through 20km+ flight conditions*	* Additional government-provided details (e.g., steady and transient heat flux, shear and normal surface loads on vehicle and control surfaces, etc.) outside scope of unclassified 6.1 research
Weapon packaging	• Conic, ogive, and cylindrical body shapes with sharp noses • Thin, swept stabilizing and control surfaces with sharp leading edges